novel method of chemical research which I have here exemplified may be considered of sufficient interest to be followed out by other investigators, and believing that the experiments and suggestions which I have here given, and the principles they involve, are calculated to throw some light on the nature of those chemical processes which take place in nature, whether in organized bodies or in the crust of the earth, neither of which branches of natural chemistry is at present sufficiently understood, and both of which it is of very high interest further to elucidate.

April 6, 1865.

Major-General SABINE, President, in the Chair.

The following communications were read:—

I. "Report on the New Unit of Electrical Resistance proposed and issued by the Committee on Electrical Standards appointed in 1861 by the British Association." By FLEEMING JENKIN, Esq. Communicated by Professor A. W. WILLIAMSON. Received March 20, 1865.

Sir Humphry Davy, in 1821*, published his researches proving a difference in the conducting-power of metals and the decrease of that power as their temperature rose. This quality of metals was examined by Snow Harris, Cumming, and E. Becquerel, whose table of conducting-powers, compiled by the aid of his differential galvanometer, and published in 1826†, is still frequently quoted, and is indeed remarkable as the result of experiments made before the publication by Ohm, in 1827‡, of the true mathematical theory of the galvanic circuit.

The idea of resistance as the property of a conductor was introduced by Ohm, who conceived the force of the battery overcoming the resistance of the conductors and producing the current as a result. Sir Humphry Davy, on the contrary, and other writers of his time, conceived the voltaic battery rather as continually reproducing a charge, somewhat analogous to that of a Leyden jar, which was discharged so soon as a conductor allowed the fluid to pass. The idea of resistance is the necessary corollary of the conception of a force doing some kind of work§, whereas the idea of conducting-power is the result of an obvious analogy when electricity is conceived as a fluid, or two fluids, allowed to pass in different quantities through different wires from pole to pole. When submitted to measurement, the

* Phil. Trans. 1821, vol. cxi. p. 425.

† Ann. de Chim. et de Phys. vol. xxxii. 2nd series, p. 420.

‡ Die galvanische Kette, mathematisch bearbeitet, 1827; also Taylor's Scientific Memoirs, vol. ii. p. 401.

§ The writer does not mean by this that electrical and mechanical resistance are truly analogous, or that a current truly represents work.

qualities of conducting-power and resistance are naturally expressed by reciprocal numbers, and the terms are used in this sense in the early writings of Lenz (1833) *, who, with Fechner †, and Pouillet ‡, established the truth of Ohm's theory shortly after the year 1830.

The conception of a unit of resistance is implicitly contained in the very expression of Ohm's law; but the earlier writers seem to have contented themselves with reducing by calculation the resistance of all parts of a heterogeneous circuit into a given length of some given part of that circuit, so as to form an imaginary homogeneous conductor, the idea of which lies at the basis of Ohm's reasoning. These writers, therefore, generally speak of the resistance as the "reduced length" of the conductor, a term still much used in France (*vide* Daguin, Jamin, Becquerel, De la Rive, and others). The next step would naturally be, when comparing different circuits, to reduce all resistances into a length of some one standard wire, though this wire might not form part of all or of any of the circuits, and then to treat the unit length of that standard wire as a unit of resistance. Accordingly we find Lenz (in 1838 §) stating that 1 foot of No. 11 copper wire is his unit of resistance, and that it is 19·9 times as great as the unit he used in 1833 *, which was a certain constant part of the old circuit. In the earlier paper the resistances are treated as lengths, in the later as so many "units."

Lenz appears to have chosen his unit at random, and apparently without the wish to impose that unit upon others. A further advance is seen when Professor Wheatstone, in his well-known paper of 1843 ‖, proposes 1 foot of copper wire, weighing 100 grains, not only as a unit, but as a standard of resistance, chosen with reference to the standard weight and length used in this country. To Professor Wheatstone also appears due the credit of constructing (in 1840) the first instruments by which definite multiples of the resistance-unit chosen might be added or subtracted at will from the circuit ‖. He was closely followed by Poggendorff ¶ and Jacobi **, the description of whose apparatus, indeed, precedes that of the Rheostat and Resistance-coils, although the writer understands that they acknowledge having cognizance of those inventions. Resistance-coils, as the means of adding, not given lengths, but given graduated resistances to any circuit, are now as necessary to the electrician as the balance to the chemist.

In 1846 Hankel †† used as unit of resistance a certain iron wire; in 1847 I. B. Cooke ‡‡ speaks of a length of wire of such section and conducting-power as is best fitted for a standard of resistance. Buff §§ and Horsford ‖‖

* Pogg. Ann. vol. xxxiv. p. 418.

† Maasbestimmungen, etc. 1 vol. 4to. Leipzic, 1831.

‡ Elémens de Physique, p. 210, 5th edition; and Comptes Rendus, vol. iv. p. 267.

§ Pogg. Ann. vol. xlv. p. 105.

‖ Phil. Trans. 1843, vol. cxxxiii. p. 303.

¶ Pogg. Ann. vol. lii. p. 511.

** Pogg. Ann. vol. lii. p. 526; vol. liv. p. 347.

†† Pogg. Ann. vol. lxix. p. 255.

‡‡ Phil. Mag. New Series, vol. xxx. p. 385.

§§ Pogg. Ann. vol. lxxiii. p. 497.

‖‖ Pogg. Ann. vol. lxx. p. 238, and Silliman's Journ. vol. v. p. 36.

in the same year reduce the resistance of their experiments to lengths of a given German-silver wire, and as a further definition they give its value as compared with pure silver. To avoid the growing inconvenience of this multiplicity of standards, Jacobi * (in 1848) sent to Poggendorff and others a certain copper wire, since well known as Jacobi's standard, desiring that they would take copies of it, so that all their results might be expressed in one measure. He pointed out, with great justice, that mere definition of the standard used, as a given length and weight of wire, was insufficient, and that good copies of a standard, even if chosen at random, would be preferable to the reproduction in one laboratory of a standard prepared and kept in another. The present Committee fully indorse this view, although the definition of standards based on weights and dimensions of given materials has since then gained greatly in precision.

Until about the year 1850 measurements of resistance were confined, with few exceptions, to the laboratory; but about that time underground telegraphic wires were introduced, and were shortly followed by submarine cables, in the examination and manufacture of which the practical engineer soon found the benefit of a knowledge of electrical laws. Thus in 1847 the officers of the Electric and International Telegraph Company used resistance-coils made by Mr. W. F. Cooke, apparently multiples of Wheatstone's original standard, which was nearly equal to the No. 16 wire of commerce; and Mr. C. F. Varley † states that, even at that date, he used a rough mode of "distance testing." In 1850, Lieut. Werner Siemens ‡ published two methods for determining, by experiments made at distant stations, the position of "a fault"—that is to say, a connexion between the earth and the conducting-wire of the line at some point between the stations. In one of these plans a resistance equal to that of the battery is used, and the addition of resistances is also suggested; and Sir Charles Bright, in a Patent dated 1852 §, gives an account of a plan for determining the position of a fault by the direct use of resistance-coils. Since that time new methods of testing for faults and of examining the quality of materials employed, and the condition of the line, have been continually invented, almost all turning, more or less, on the measurement of resistance; greater accuracy has been continually demanded in the adjustment of coils and other testing-apparatus, until we have now reached a point where we look back with surprise at the rough and ready means by which the great discoveries were made on which all our work is founded.

The first effect of the commercial use of resistance was to turn the "feet" of the laboratory into "miles" of telegraph wire. Thus we find employed as units, in England the mile of No. 16 copper wire ||, in Germany the German mile of No. 8 iron wire, and in France the kilometre of iron wire

* Comptes Rendus, 1851, vol. xxxiii. p. 277. † Letter to writer, 1865.

‡ Pogg. Ann. vol. lxxix. p. 481. § Patent No. 14,331, dated Oct. 21, 1852.

|| A size much used in underground conductors, and equal in resistance to about double the length of the common No. 8 iron wire employed in aërial lines.

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APPENDIX A.—Relative Valu

Description.	Name.	Absolute $\frac{\text{foot}}{\text{second}} \times 10^7$.	Thomson's old unit.	Jacobi.	Weber's absolute $\frac{\text{metre}}{\text{second}} \times 10^7$.	Siemens 1864 issue.	Sieme (Berli
Absolute $\frac{\text{foot}}{\text{second}} \times 10^7$ electro-magnetic units (new determination)	Absolute $\frac{\text{foot}}{\text{second}} \times 10^7$.	1·000	0·9520	0·4788	0·3316	0·3187	0·31
Absolute $\frac{\text{foot}}{\text{second}} \times 10^7$ electro-magnetic units (old determination)	Thomson's unit	1·0505	1·000	0·5029	0·3483	0·3336	0·33
Twenty-five feet of a certain copper wire, weighing 345 grains...	Jacobi	2·088	1·988	1·000	0·6925	0·6655	0·66
Absolute $\frac{\text{metre}}{\text{second}} \times 10^7$ electro-magnetic units determined by Weber (1862)................................	Weber's absolute $\frac{\text{metre}}{\text{second}} \times 10^7$	3·015	2·871	1·444	1·000	0·9607	0·95
One metre of pure mercury, one square millimetre section at 0° C.	Siemens 1864 issue......	3·149	2·988	1·503	1·041	1·000	0·99
One metre of pure mercury, one square millimetre section at 0° C.	Siemens (Berlin)	3·156	3·004	1·511	1·046	1·005	1·00
One metre of pure mercury, one square millimetre section at 0° C.	Siemens (London)	3·194	3·040	1·529	1·059	1·017	1·01
British Association unit	B. A. unit, or Ohmad...	**3·281**	**3·123**	**1·5706**	**1·088**	**1·0456**	**1·0**
One kilometre of iron wire, four millimetres in diameter (temperature not known)	Digney......................	30·40	28·94	14·56	10·08	0·0968	9·63
One kilometre of iron wire, four millimetres in diameter (temperature not known).................	Bréquet	32·03	30·50	15·34	10·62	10·20	10·15
One kilometre of iron wire, four millimetres in diameter (temperature not known)..................	Swiss	34·21	32·56	16·38	11·34	10·90	10·84
One English standard mile of pure annealed copper wire $\frac{1}{16}$ in. diameter at 15°·5 C.	Matthiessen..............	44·57	42·43	21·34	14·78	14·19	14·12
One English standard mile of one special copper wire $\frac{1}{16}$ inch in diameter..............................	Varley	84·01	79·96	40·21	27·85	26·75	26·61
One German mile=8238 yards of iron wire $\frac{1}{6}$ inch in diameter (temperature not known*)	German mile	188·4	179·4	90·22	62·48	60·03	59·71

* Messrs. Siemens do not now manufacture coils with this unit, wh

Appendix A.—Relative Values of various Units of Electrical Resistance.

Thomson's old unit.	Jacobi.	Weber's absolute $\frac{\text{metre}}{\text{second}} \times 10^7$.	Siemens 1864 issue.	Siemens (Berlin).	Siemens (London).	B. A. unit, or Ohmad.	Digney.	Bréquet.	Swiss.	Matth
0·9520	0·4788	0·3316	0·3187	0·3168	0·3131	0·3048	0·03289	0·03123	0·02924	0·0
1·000	0·5029	0·3483	0·3336	0·3328	0·3289	0·3202	0·03455	0·03279	0·03071	0·0
1·988	1·000	0·6925	0·6655	0·6618	0·6540	0·6367	0·06869	0·06520	0·06106	0·0
2·871	1·444	1·000	0·9607	0·9556	0·9443	0·9191	0·09919	0·09416	0·08817	0·0
2·988	1·503	1·041	1·000	0·9950	0·9829	0·9563	0·1033	0·09799	0·09177	0·0
3·004	1·511	1·046	1·005	1·000	0·9881	0·9615	0·1038	0·09852	0·09227	0·0
3·040	1·529	1·059	1·017	1·012	1·000	0·9736	0·1050	0·0997	0·09337	0·0
3·123	**1·5706**	**1·088**	**1·0456**	**1·040**	**1·027**	**1·000**	**0·10792**	**0·10245**	**0·09593**	**0·**
28·94	14·56	10·08	0·0968	9·634	9·520	9·266	1·000	0·9491	0·8889	0·6
30·50	15·34	10·62	10·20	10·15	10·13	9·760	1·054	1·000	0·9365	0·7
32·56	16·38	11·34	10·90	10·84	10·71	10·42	1·125	1·068	1·000	0·7
42·43	21·34	14·78	14·19	14·12	13·95	13·59	1·66	1·391	1·303	1·0
79·96	40·21	27·85	26·75	26·61	26·30	25·61	2·763	2·622	2·456	1·8
179·4	90·22	62·48	60·03	59·71	59·00	57·44	6·198	5·882	5·509	4·2

* Messrs. Siemens do not now manufacture coils with this unit, which has been abandoned by them in favour of the mercury unit given above.

Units of Electrical Resistance.

B. A. unit, or Ohmad.	Digney.	Bréquet.	Swiss.	Matthiessen.	Varley.	German Miles.	Observations.
0·3048	0·03289	0·03123	0·02924	0·02243	0·01190	0·005307	Calculated from the B. A. unit.
0·3202	0·03455	0·03279	0·03071	0·02357	0·01251	0·005574	From an old determination by Weber.
0·6367	0·06869	0·06520	0·06106	0·04686	0·02486	9·01108	No measurement made; ratio between Siemens (Berlin) and Jacobi taken from "Weber's Galvanometrie."
0·9191	0·09919	0·09416	0·08817	0·06767	0·03591	0·01655	Measurement taken from a determination in 1862 of a standard sent by Prof. Thomson; does not agree with Weber's own measurement of Siemens's units; by Weber 1 Siemens's unit $=1·025\times10^7$ metres-second.
0·9563	0·1033	0·09799	0·09177	0·07047	0·03737	0·01666	Measurement taken from three coils issued by Messrs. Siemens.
0·9615	0·1038	0·09852	0·09227	0·07081	0·03757	0·01675	Measurement taken from coils exhibited in 1862 by Messrs. Siemens, Halske & Co. (well adjusted).
0·9736	0·1050	0·0997	0·09337	0·07166	0·03802	0·01695	Measurement taken from coils exhibited in 1862 by Messrs. Siemens, Halske & Co. (well adjusted).
1·000	**0·10792**	**0·10245**	**0·09593**	**0·0736**	**0·03905**	**0·01741**	Equal to 10,000,000 $\frac{\text{metres}}{\text{second}}$ according to experiments of Standard Committee.
9·266	1·000	0·9491	0·8889	0·6822	0·3620	0·1613	From coils exhibited in 1862 (pretty well adjusted).
9·760	1·054	1·000	0·9365	0·7187	0·3814	0·1700	From coils exhibited in 1862 (indifferently adjusted).
10·42	1·125	1·068	1·000	0·7675	0·4072	0·1815	From coils exhibited in 1862 (badly adjusted).
13·59	1·66	1·391	1·303	1·000	0·5306	0·2365	From a coil lent by Dr. Mattheissen (of German-silver wire).
25·61	2·763	2·622	2·456	1·885	1·000	0·4457	From coils lent by Mr. Varley (well adjusted).
57·44	6·198	5·882	5·509	4·228	2·243	1·000	From coils exhibited in 1862 by Messrs. Siemens, Halske & Co.*

doned by them in favour of the mercury unit given above.

of 4 millimetres diameter. Several other units were from time to time proposed by Langsdorf *, Jacobi †, Marié-Davy ‡, Weber §, W. Thomson ‖, and others, with a gradually increasing perception of the points of chief importance in a standard; but none of these were generally accepted as the one recognized measure in any country. To remedy the continually increasing evils arising from the discrepancies invariably found between different sets of coils, Dr. Werner Siemens (in 1860 ¶) constructed standards, taking as unit the resistance of a column of chemically pure mercury 1 metre long, having a section equal to 1 millimetre square, and maintained at the temperature of 0° Centigrade **. Dr. Siemens supposed that this standard could be reproduced without much difficulty where copies could not be directly obtained. Mercury had been proposed before as a fitting material for a standard by Marié-Davy and De la Rive; but Dr. Siemens merits especial recognition, as the coils and apparatus he issued have been made with great care, and have materially helped in introducing strict accuracy ††.

The question had reached this point when (in 1861) the British Association, at the suggestion of Professor W. Thomson, appointed a Committee to determine the best standard of electrical resistance. This Committee, aided by a grant from the Royal Society, has now issued a new standard, the subject of the present paper.

The writer has hitherto described those units only which are founded on a more or less arbitrary size and weight of some more or less suitable material; but measurements of resistance can be conceived and carried out entirely without reference to the special qualities of any material whatever. In 1849 Kirchhoff ‡‡ had already effected a measurement of this kind; but it is to W. Weber §§ that we owe the first distinct proposal (in 1851) of a definite system of electrical measurements, according to which resistance would be measured in terms of an absolute velocity. This system of measures he called absolute electromagnetic measure, in analogy with Gauss's nomenclature of absolute magnetic measure. The Committee have decided that Weber's proposal is far preferable to the use of any unit of the kind previously described. Setting aside the difficulties in the way of their

* Liebig's Ann. vol. lxxxv. p. 155.

† Pogg. Ann. vol. lxxviii. p. 173.

‡ Ann. Chim. et Phys. 3rd series, vol. ix. p. 410.

§ Pogg. Ann. vol. lxxxii. p. 337.

‖ Phil. Mag. Dec. 1851, 4th ser. vol. ii. p. 551.

¶ Pogg. Ann. vol. cx. p. 1.

** Dr. Siemens, while retaining his definition, has altered the value of his standard about 2 per cent. since the first issue; and it is doubtful whether even the present standard represents the definition truly: his experiments were made by weight; and in reducing the results to simple measurements of length he has used a specific gravity for mercury of 13·557 instead of 13·596 as given by Regnault, 13·595 by H. Kopp, and 13·594 by Balfour Stewart.

†† Many of the different units described above were represented by resistance-coils in the International Exhibition of 1862: *vide* Jury Report, Class XIII. p. 83, where their relative values are given: *vide* also Appendix A. to present paper.

‡‡ Pogg. Ann. vol. lxxvi. p. 412.

§§ Ibid. vol. lxxxii. p. 337.

reproduction, which are by no means contemptible, arbitrary material standards, whether of mercury, gold, silver, platinum, or any other material, would be heterogeneous isolated units without any natural connexion with any other physical units. The unit proposed by Weber, on the other hand, forms part of a symmetrical natural system, including both the fundamental units of length, time, and mass, and the derived electrical units of current quantity and electromotive force. Moreover it has been shown by Professor W. Thomson*, who accepted and extended Weber's proposal immediately on its appearance, that the unit of absolute work, the connecting link between all physical forces, forms part of the same system, and may be used as the basis of the definition of the absolute electromagnetic units.

The full grounds of the choice of the Committee could only be explained by a needless repetition of the arguments given in the reports already made to the British Association. It will be sufficient here to state that, in the absolute electromagnetic system, the following equations exist between the mechanical and electrical units:—

$$W = C^2Rt, \qquad (1)$$

where W is the work done in the time t by the current C conveyed through a conductor of the resistance R. This equation expresses Joule and Thomson's law.

$$C = \frac{E}{R}, \qquad (2)$$

where E is the electromotive force. This equation expresses Ohm's law.

$$Q = Ct, \qquad (3)$$

expressing a relation first proved by Faraday, where Q is the quantity of electricity conveyed or neutralized by the current in the time t. Finally, the whole system is rendered determinate by the condition that the unit length of the unit current must produce the unit force on the unit pole (Gauss) at the unit distance. If it is preferred to omit the conception of magnetism, this last statement is exactly equivalent to saying that the unit current conducted round two circles of unit area in vertical planes at right angles to each other, one circuit being at a great distance D above the other, will cause a couple to act between the circuits of a magnitude equal to the reciprocal of the cube of the distance D. This last relation expresses the proposal made by Weber for connecting the electric and magnetic measure. These four relations serve to define the four magnitudes R, C, Q, and E, without reference to any but the fundamental units of time, space, and mass; and when reduced to these fundamental units, it will be found that the measurement of R involves simply a velocity, *i.e.* the quotient of a length by a time. It is for this reason that the absolute

* Phil. Mag. Dec. 1851, 4th series, vol. ii. p. 551.

measure of resistance is styled $\frac{\text{metre}}{\text{second}}$ or $\frac{\text{foot}}{\text{second}}$, precisely as the common non-absolute unit of work involving the product of a weight into a length is styled kilogrammetre or foot-pound. The Committee have chosen as fundamental units the second of time, the metre, and the mass of the Paris gramme. The metrical rather than the British system of units was selected, in the hope that the new unit might so find better acceptance abroad, and with the feeling that while there is a possibility that we may accept foreign measures, there is no chance that the Continent will adopt ours. The unit of force is taken as the force capable of producing in one second a velocity of one metre per second in the mass of a Paris gramme, and the unit of work as that which would be done by the above force acting through one metre of space. These points are very fully explained in the British Association Report for 1863, and in the Appendix C to that Report by Professor J. Clerk Maxwell and the writer.

The magnitude of the $\frac{\text{metre}}{\text{second}}$ is far too small to be practically convenient, and the Committee have therefore, while adopting the system, chosen as their standard a decimal multiple 10^{10} times as great as Weber's unit $\left(\text{the } \frac{\text{millimetre}}{\text{second}}\right)$, or 10^7 times as great as the $\frac{\text{metre}}{\text{second}}$. This magnitude is not very different from Siemens's mercury unit, which has been found convenient in practice. It is about the twenty-fifth part of the mile of No. 16 impure copper wire used as a standard by the Electric and International Company, and about once and a half Jacobi's unit*.

It was found necessary to undertake entirely fresh experiments in order to determine the actual value of the abstract standard, and to express the same in a material standard which might form the basis of sets of resistance-coils to be used in the usual manner. These experiments, made during two years with two distinct sets of apparatus by Professor J. C. Maxwell and the writer, according to a plan devised by Professor W. Thomson, are fully described in the Reports to the British Association for 1863 and 1864.

The results of the two series of experiments made in the two years agree within 0·2 per cent., and they show that the new standard does not probably differ from true absolute measure by 0·1 per cent†. It is not far from the mean of a somewhat widely differing series of determinations by Weber.

In order to avoid the inconvenience of a fluctuating standard, it is proposed that the new standard shall not be called "absolute measure," or described as so many $\frac{\text{metre}}{\text{seconds}}$, but that it shall receive a distinctive name, such as the B. A. unit, or, as Mr. Latimer Clark suggests, the "Ohmad," so

* This last number may be 30 per cent. wrong, as the writer has never been in possession of an authenticated Jacobi standard, and has only arrived at a rough idea of its value by a series of published values which afford an indirect comparison.

† *Vide* Appendix B.

that, if hereafter improved methods of determination in absolute measure are discovered or better experiments made, the standard need not be changed, but a small coefficient of correction applied in those cases in which it is necessary to convert the B. A. measure into absolute measure. Every unit in popular use has a distinctive name; we say feet or grains, not units of length or units of weight; and it is in this way only that ambiguity can be avoided. There are many absolute measures, according as the foot and grain, the millimetre and milligramme, the metre and gramme, &c. are used as the basis of the system. Another chance of error arises from the possibility of a mistake in the decimal multiple used as standard. For all these reasons, as well as for convenience of expression, the writer would be glad if Mr. Clark's proposal were adopted and the unit called an Ohmad.

Experiments have been made for the Committee by Dr. Matthiessen, to determine how far the permanency of material standards may be relied on, and under what conditions wires unaltered in dimension, in chemical composition, or in temperature change their resistance. Dr. Matthiessen has established that in some metals a partial annealing, diminishing their resistance, does take place, apparently due to age only. Other metals exhibit no alteration of this kind; and no permanent change due to the passage of voltaic currents has been detected in any wires of any metal—a conclusion contrary to a belief which has very generally prevailed.

The standard obtained has been expressed in platinum, in a gold-silver alloy, in a platinum-silver alloy, in a platinum-iridium alloy, and in mercury. Two equal standards have been prepared in each metal; so that should time or accident cause a change in one or more, this change will be detected by reference to the others. The experiments and considerations which have led to the choice of the above materials are fully given in the Report to the British Association for 1864. The standards of solid metals are wires of from 0·5 millim. to 0·8 millim. diameter, and varying from one to two metres in length, insulated with white silk wound round a long hollow bobbin, and then saturated with solid paraffin. The long hollow form chosen allows the coils rapidly to assume the temperature of any surrounding medium, and they can be plunged, without injury, into a bath of water at the temperature at which they correctly express the standard. The mercury standards consist of two glass tubes about three-quarters of a metre in length. All these standards are equal to one another at some temperature stated on each coil, and lying between 14°·5 and 16°·5 C. None of them, when correct, differ more than 0·03 per cent. from their value at 15°·5 C.

Serious errors have occasionally been introduced into observations by resistance at connexions between different parts of a voltaic circuit, as perfect metallic contact at these points is often prevented by oxide or dirt of some kind. Professor Thomson's method of inserting resistances in the Wheatstone balance (differential measurer) has been adopted for the standards, but

in the use of the copies which have been issued it has been thought that sufficient accuracy would be attained by the use of amalgamated mercury connexions.

In the standards themselves permanence is the one paramount quality to be aimed at; but in copies for practical use a material which changes little in resistance with change of temperature is very desirable, as otherwise much time is lost in waiting till coils have cooled after the passage of a current; moreover large corrections have otherwise to be employed when the coils are used at various temperatures; and these temperatures are frequently not known with perfect accuracy. German silver, a suitable material in this respect, and much used hitherto, has been found to alter in resistance, in some cases, without any known cause but the lapse of time, since the change has been observed where the wires were carefully protected against mechanical or chemical injury. A platinum-silver alloy has been preferred by the Committee to German silver for the copies which have been made of the standard. These have been adjusted by Dr. Matthiessen so as to be correct at some temperature not differing more than 1° from 15°·5 C. The resistance of platinum-silver changes about 0·031 per cent. for each degree Centigrade within the limits of 5° above and below this temperature; this change is even less than that of German silver. The new material seems also likely to be very permanent, as it is little affected by annealing. The form of the copies is the same as that of the standard, with the exception of the terminals, which are simple copper rods ending in an amalgamated surface. Twenty copies have been distributed gratis, and notices issued that others can be procured from the Committee for £2 10*s*. The Committee also propose to verify, at a small charge, any coils made by opticians, as is done for thermometers and barometers at Kew.

Dr. Matthiessen reports, with reference to the question of reproduction, that given weights and dimensions of several pure metals might be employed for this purpose *if absolute care were taken*. The reproduction, in this manner, of the mercury unit, as defined by Dr. Siemens, differs from the standards issued by him in 1864 about 8·2 per thousand if the same specific gravity of mercury be used for both observations*. Each observer uses for his final value the mean of several extremely accordant results. It is therefore to be hoped that the standard will never have to be reproduced by this or any similar method. On the other hand, four distinct observers, with four different apparatus, using four different pairs of standards issued respectively by Dr. Siemens and the Committee, give the B. A. unit as respectively equal to 1·0456, 1·0455, 1·0456, and 1·0457 of Siemens's 1864 unit. It is certain that two resistances can be compared with an accuracy of one part in one hundred thousand—an accuracy wholly unattainable in any reproduction by weights and measures of a given body, or by fresh reference to experiments on the absolute resistance. The above four com-

* If Dr. Matthiessen uses the sp. gr. of 13·596, as given by Regnault, the difference from Dr. Siemens's standard is 5 per thousand.

parisons, two of which were made by practical engineers, show how far the present practice and requirements differ from those of twenty and even ten years ago, when, although the change of resistance due to change of temperature was known, it was not thought necessary to specify the temperature at which the copper or silver standard used was correct. The difficulty of reproducing a standard by simple reference to a pure metal, further shows the unsatisfactory nature of that system in which the conducting-power of substances is measured by comparison with that of some other body, such as silver or mercury. Dr. Matthiessen has frequently pointed out the discrepancies thus produced, although he has himself followed the same system pending the final selection of a unit of resistance. It is hoped that for the future this quality of materials will always be expressed as a specific resistance or specific conducting-power referred to the unit of mass or the unit of volume, and measured in terms of the standard unit resistance, that the words conducting-power will invariably be used to signify the reciprocal of resistance, and that the vague terms good and bad conductor or insulator will be replaced, in all writings aiming at scientific accuracy, by those exact measurements which can now be made with far greater ease than equally accurate measurements of length.

There is every reason to believe that the new standard will be gladly accepted throughout Great Britain and the colonies. Indeed the only obstacle to its introduction arises from the difficulty of explaining to inquirers what the unit is. The writer has been so much perplexed by this simple question, finding himself unable to answer it without entering at large on the subject of electrical measurement, that he has been led to devise the following definitions, in which none but already established measures are referred to.

The resistance of the absolute $\frac{\text{metre}}{\text{second}}$ is such that the current generated in a circuit of that resistance by the electromotive force due to a straight bar 1 metre long moving across a magnetic field of unit intensity* perpendicularly to the lines of force and to its own direction with a velocity of 1 metre per second, would, if doing no other work or equivalent of work, develope in that circuit in one second of time a total amount of heat equivalent to one absolute unit of work—or sufficient heat, according to Dr. Joule's experiments, to heat 0·0002405 gramme of water at its maximum density 1° Centigrade.

The new standard issued is as close an approximation as could be obtained by the Committee to a resistance ten million times as great as the absolute $\frac{\text{metre}}{\text{second}}$. The straight bar moving as described above in a magnetic field of unit intensity, would require to move with a velocity of ten millions of metres per second to produce an electromotive force which would generate in a circuit of the resistance of the new standard the same

* Gauss's definition.

current as would be produced in the circuit of one $\frac{\text{metre}}{\text{second}}$ resistance by the electromotive force due to the motion of the bar at a velocity of one metre per second. The velocity required to produce this particular current* being in each case proportional to the resistance of the circuit, may be used to measure that resistance, and the resistance of the B. A. unit may therefore be said to be ten millions of metres per second, or $10^7 \frac{\text{metres}}{\text{second}}$.

It is feared that these statements are still too complex to fulfil the purpose of popular definitions, but they may serve at least to show how a real velocity may be used to measure a resistance by using the velocity with which, under certain circumstances, part of a circuit must be made to move in order to induce a given current in a circuit of the resistance to be measured. That current in the absolute system is the unit current, and the work done by that unit current in the unit of time is equal to the resistance of the circuit, as results from the first equation stated above.

Those who from this slight sketch may desire to know more of the subject will find full information in the Reports of the Committee to the British Association in 1862, 1863, and 1864. The Committee continue to act with the view of establishing and issuing the correlative units of current, electromotive force, quantity, and capacity, the standard apparatus for which will, it is proposed, be deposited at Kew along with the ten standards of resistance already constructed with the funds voted by the Royal Society.

Appendix B.

The following Table shows the degree of concordance obtained in the separate experiments used to determine the unit. The determinations were made by observing the deflections of a certain magnet when a coil revolved at a given speed, first in one direction, and then in the opposite direction. The first column shows the speed in each experiment; the second shows the value of the B. A. unit in terms of $10^7 \frac{\text{metres}}{\text{second}}$, as calculated from the single experiments. A difference constantly in one direction may be observed in the values obtained when the coil revolved different ways. This difference depended on a slight bias of the suspending thread in one direction. The third column shows the value of the B. A. unit calculated from the pair of experiments. The fourth shows the error of the pair from the mean value finally adopted. In the final mean adopted, the 1864 determination was allowed five times the weight allowed to that of 1863.

* This current is the unit current, and, if doing no other work or equivalent of work, would develope, in a circuit of the resistance of the B. A unit, heat equivalent to ten millions of units of work, or enough to raise the temperature of 2405 grammes of water at its maximum density 1° Centigrade.

1. Time of 100 revolutions of coil, in seconds.	2. Value of B. A. unit in terms of $10^7 \frac{\text{metres}}{\text{second}}$, as calculated from each experiment.	3. Value from mean of each pair of experiments.	4. Percentage error of pair of observations from mean value.
17·54 17·58	1·0121 0·9836	0·9978	−0·22
77·62 76·17	1·0468 0·9613	1·0040	+0·40
53·97 54·53	0·9985 0·9998	0·9992	−0·08
41·76 41·79	0·9915 0·9936	0·9925	−0·75
54·07 53·78	0·9961 0·9886	0·9924	−0·76
17·697 17·783	0·9878 1·0136	1·0007	+0·07
17·81 17·78	0·9952 1·0174	1·0063	+0·63
17·01 16·89	1·0191 0·9895	1·0043	+0·43
21·35 21·38	1·0034 1·0011	1·0022	+0·22
21·362 21·643	0·9968 1·0096	1·0040	+0·40
11·247 16·737	1·0424 0·9707	0·9981	−0·19

Probable error of R (1864).......... =0·1 per cent.
Probable error of R (1863).......... =0·24 „
Difference in two values 1864 and 1863=0·16 „
Probable error of two experiments .... =0·08 „

II. "Researches on the Hydrocarbons of the Series $C_n H_{2n+2}$." By C. SCHORLEMMER, Esq., Assistant in the Laboratory of Owens College, Manchester. Communicated by Prof. H. E. ROSCOE, F.R.S. Received March 21, 1865.

Previously to the year 1848 none of the members of the numerous family of hydrocarbons of the general formula $C_n H_{2n+2}$, with the single exception of marsh-gas, were known to the chemist; but since that year the researches of Kolbe on the electrolysis of the fatty acids, and those of Frankland on the action of zinc upon the alcohol iodides, have opened up a new field of discovery, from which in rapid succession rich harvests have been reaped. The hydrocarbons thus isolated were considered by their discoverers to be the true radicals of the alcohols; and in consequence the molecular weights which were then given to these bodies amounted only to half those which are now generally accepted.